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Relation of the Depth to Which the Soil is Wet at Seeding Time to the Yield of Spring Wheat on the Great Plains

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INTRODUCTION

The control that may be exercised by the initial water content of the soil over the yields of spring-sown small grains, of which wheat is the typical representative, on the Great Plains is a question of the utmost importance. If the water content of the soil at seeding time is an indicator of the order of yield that may be expected, knowledge of that condition may be used as a guide to practice, by which the chances of seeding a crop with a high expectation of failure or unsatisfactory yield may be materially reduced and advantage may be taken of favorable indications to seed normal or above-normal acreages.

The studies and publications of Hallsted and Mathews (*6*),[1] Hallsted (*5*), and Mathews and Brown (*8*) show the high degree of control exercised over the yields of winter wheat in the southern and central Great Plains by the depth to which the soil is wet at seeding time. The latter is for practical purposes, under the soil and climatic conditions obtaining in the Great Plains, a measure of the available water that is stored in the soil at the time of determination. The simplification of this measure to a visual observation of the depth of wet soil and the direct translation of that observation into two or three categories of yield and chances of failure undoubtedly were

[1] Italic numbers in parentheses refer to Literature Cited, p. 14.

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responsible for the widespread acceptance of the guides to practice afforded by it.

In a later publication Mathews and Barnes (*7*) show that at a representative station (Dalhart, Tex.) the available water in the soil at seeding time is a close determinant of the crop of milo that will be harvested.

The authors, studying the daily rate of use of water by spring wheat on the Great Plains (*3*), showed that there was a high correlation between the total use of water and the yield. In that study the difference between the water in the soil at seeding time and that at harvesttime, added to the total precipitation during the interval, constituted the total water used. They showed further that the total quantity is seldom more than sufficient for the needs of the crop.

Thysell (*9*) has made an important contribution to knowledge of the effects of different tillage methods and crops on the quantity of water in the soil at seeding time, and to its exhaustion by crops. He gave yields in pounds of total crop (grain plus straw harvested with a binder).

The senior author (*2*), using data from 19 field stations in the Great Plains for a total of 387 crop years, demonstrated a high degree of correlation between precipitation for the crop year and three indexes of yield of spring wheat. It was shown in this study that fallowing, which stores water in the soil in advance of the crop year, reduced the dependence of the crop on precipitation during the crop year and increased yields in the northern Plains an average of about 7 bushels per acre above yields obtained by continuous cropping.

MATERIAL FOR AND METHODS OF STUDY

The Division of Dry Land Agriculture and cooperating State agricultural experiment stations [2] have accumulated in continuous records covering more than 30 years a large volume of data on the moisture content of the soil and the yields of crops in which the control exercised by the initial (springtime) water content of the soil over the yield of spring wheat may be studied.

The present study is confined to spring wheat on 3 methods of soil preparation at 15 field stations (considering for this purpose the 2 fields at Mandan, N. Dak., as separate stations) for those years from 1907 to 1938 in which the moisture content of the soil was determined at a suitable time in the spring and when the crop was not destroyed or the yield seriously impaired by hail or rust. The locations of these and other stations in the Great Plains at which the Division has conducted experiments are shown in figure 1. So far as affected by variety or cultural treatment the yields are highly comparable between years and stations. This is more fully discussed in United States Department of Agriculture Technical Bulletin 636 (*2*). Soil moisture was determined in units of foot sections of depth, each determination being based on 4 cores of soil taken with a King soil tube having a cutting edge 20 mm. in diameter. The standard depth of sampling was 6 feet, but some samples were taken to greater depth, and at some stations the character of the soil either prevented going to that depth or the water content made it unnecessary.

[2] The data from Montana, North Dakota, Wyoming, Nebraska, and Colorado were obtained in cooperation with the agricultural experiment stations of the respective States.

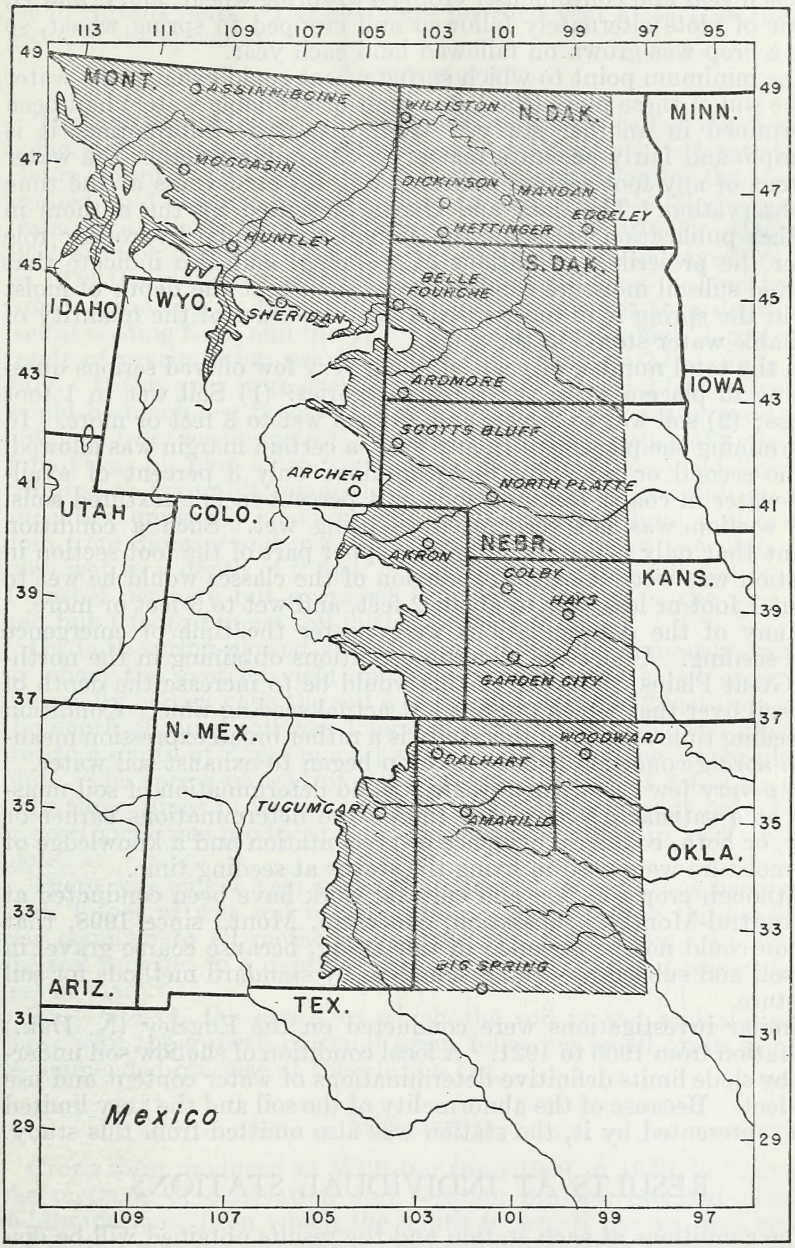

FIGURE 1.—Sketch map of the Great Plains showing the location of field stations at which the Division of Dry Land Agriculture has conducted experiments.

The three plots or methods studied were A, plowed in the spring each year and continuously cropped to spring wheat; B, plowed in the fall each year and continuously cropped to spring wheat; and C and D, a pair of plots alternately fallowed and cropped to spring wheat, so that a crop was grown on fallowed land each year.

The minimum point to which spring wheat could exhaust the water in the soil of these plots (the lower limit of available water) had been determined in another study.[3] With this basic information, it is a simple and fairly accurate matter to determine whether the water content of any foot section indicates wetness or dryness at the time of observation. The data and charts presented by the authors in another publication (*4*) show the annual or biennial hydrologic role under the prescribed conditions of cropping, and also indicate that soil and subsoil moisture conditions are such that the depth of moist soil in the spring is in most cases a good measure of the quantity of available water stored in the soil.

In the total number of years studied, very few offered serious question as to placement in the three categories: (1) Soil wet to 1 foot or less; (2) soil wet to 2 feet; and (3) soil wet to 3 feet or more. In determining the placement in any year, a certain margin was allowed. If the second or the third foot contained only 3 percent of available water in coarse-textured soils or 4 percent in fine-textured soils, that section was not recognized as being wet. Such a condition meant that only a few inches of the upper part of the foot section in question was wet. Correct expression of the classes would be wet to about 1 foot or less, wet to about 2 feet, and wet to 3 feet or more.

Many of the determinations were nearer the time of emergence than seeding. Under the climatic conditions obtaining in the northern Great Plains, the trend of this would be to increase the depth of wet soil over that which obtained at actual seeding time. Condition at seeding time as used in this study is a rather broad expression meaning a spring condition before the crop began to exhaust soil water.

In a very few cases where there was no determination of soil moisture at a satisfactory date but there were determinations earlier or later, or both, collateral evidence of precipitation and a knowledge of soil moisture were used in fixing the status at seeding time.

Although crop rotation and cultural work have been conducted at the central-Montana substation, Moccasin, Mont., since 1908, that station could not be included in this study, because coarse gravel in the soil and subsoil prevented sampling by standard methods for soil moisture.

Similar investigations were conducted on the Edgeley (N. Dak.) substation from 1906 to 1921. A local condition of shallow soil underlain by shale limits definitive determinations of water content and use to 2 feet. Because of the abnormality of the soil and the very limited area represented by it, the station was also omitted from this study.

RESULTS AT INDIVIDUAL STATIONS

The conditions at each station and the results obtained will be discussed briefly, with special consideration being given to the size of the sample, the reasons for short records or for the omission of certain

[3] Unpublished data in the files of the Division of Dry Land Agriculture.

years, the general trend of results, and exceptional or unusual behavior in certain years. Detailed data for each year at each station are given in the appendix.

Assinniboine

The northern Montana branch station, herein called the Assinniboine station in keeping with previous publications, is located near Havre, Mont. The precipitation is the lowest of any of the stations studied, and the soil has a medium to high water-holding capacity. Data are available for 22 years during the period 1916–38. Data for 1934 are not used, because the crop was seriously damaged by hail. In 1916 the plots had uniform preparation, all being on land broken from prairie sod in June 1915. All plots were wet to a depth of 2 feet at seeding time, and the yields were abnormally high, largely as a result of precipitation nearly double the normal in May, June, and July. If this year were excluded, the showing from 2 feet of wet soil would be much less favorable than it is. The only really good yield obtained from seeding in soil that was not wet to a depth of more than 1 foot was on plot A, spring-plowed, in 1932. This yield "was attributed to favorable quantities and distribution of rainfall in April and May, unusually heavy rainfall (4.50 inches) in June, and to freedom from diseases and insects" (*2, p. 7*). The other two plots were each wet to a depth of 2 feet. The yields on them differed by only 1 bushel per acre but averaged 5 bushels more than the plot that had but 1 foot of moist soil in the spring.

On both spring-plowed and fall-plowed land continuously cropped to wheat the average yield and the expectancy of a fair crop were materially higher when the soil was wet to a depth of 2 feet than when the depth of moist soil was 1 foot or less. The fall-plowed plot was wet to a depth of 2 feet much less frequently than the spring-plowed plot. The spring-plowed plot was wet to a depth of 3 feet or more only three times in its history and the fall-plowed plot only twice. A good yield was produced from this condition only in 1927 on both plots.

There was only 1 year when the fallowed plot did not have more than 1 foot of wet soil in the spring. In that year the condition was common to all methods, and the yields were low. In 8 years the soil was wet to a depth of 2 feet, and in 13 years it was wet to 3 feet or more.

The data on the depth to which the soil is wet and the yields show why the growth of small grain following small grain is not a recommended practice at this station (*1*).

Williston

Crops were produced at Williston from 1909 to 1920, inclusive, in the methods of cultivation and rotation project, but soil-moisture determinations, from which the depth to which the soil was wet in the spring may be estimated, are available for the 7 years 1910–16 only. Near failures were experienced in the 2 years when available water in the continuously cropped plots was limited to the first foot, and good yields in the 5 years when the soil was wet to a depth of 2 or 3 feet. In 1910 and 1911 when available water in the continuously cropped plots was limited to the first foot, the fallowed plot

was wet 3 and 2 feet, respectively. The yields were higher than on the continuously cropped plots but were of low order. In the other 5 years the fallowed plot had 3 feet or more of wet soil, and the yields were somewhat higher than those on the continuously cropped plots.

Huntley

Data from the Huntley station are available for all but 1 of the 27 years 1912–38. There were no soil-moisture determinations in the spring of 1917. On land continuously cropped to wheat water seldom penetrates to a depth of more than 2 feet. In about half the years the depth of wet soil did not exceed 1 foot, and in only one of these was a good yield obtained. In one other year when this condition obtained the spring-plowed plot produced 11.0 bushels and the fall-plowed plot 7.8 bushels. When the soil was wet 2 feet deep there was something less than an even chance of getting a good yield.

On fallowed land there were about the same number of years with 2 feet of wet soil as on continuously cropped ground, but there was a sharp decrease in the number of years with 1 foot of wet soil and an increase in the number having 3 feet or more of wet soil.

During the 8 years 1930–37 the third foot was not wet even on fallowed land, and the crop failed or yields were very low.

Dickinson

During the period 1907–38 in which crops have been grown on the Dickinson station there are 21 years in which data are available for the present study. In 1912 and 1914 the crops were destroyed or severely damaged by hail. In 1931 cutworms destroyed the normal crop and necessitated a late reseeding. Other years from 1918 to 1938 are omitted because soil-moisture determinations at an appropriate time in the spring are lacking.

There was a proportionate increase in average yields with successive increases in the depth of wet soil in the spring. At this station 3 feet or more of wet soil provides as high a degree of assurance of a satisfactory yield as can be expected, and 2 feet of moist soil offers better than an even chance of such a return.

Mandan

Data are available from two fields at Mandan. The soil of the main field is light, and that of the south field is heavy. A 24-year record is available from the main field and a 20-year record from the south field. The average penetration of water is greater in the main than in the south field and yields are higher (*2, 9*). On land continuously cropped to wheat the soil is wet to a depth of 2 feet much more frequently on spring-plowed than on fall-plowed land in the main field. The record on fall-plowed land in the south field is too short for adequate comparison. In both fields 3 feet or more of wet soil provides a high degree of assurance of a crop. With less than 3 feet of moist soil in the spring, the average yields are materially lower and the chances of failure or a low yield are greatly increased.

Hettinger

Data for only 8 years, 1912–19, are available for study at Hettinger. In 1915 all plots produced good crops regardless of the depth of moist soil in the spring, and in 1916 the yields on all were very low, although the soil of each was wet to 3 feet or more in the spring. A comparison of the continuously cropped plots with the fallowed plot in 1917, 1918, and 1919 shows sharp contrast in the yields from soil wet only in the first foot and those from soil wet to a depth of 3 feet or more. The record at this station is too short to be in itself more than indicative.

Sheridan

The record at Sheridan is complete for the 22 years 1917–38, except for 1927 when the soil moisture in the spring was not determined. The results are very clear cut in showing only failures or near failures from 1 foot of wet soil, numerous low yields and an occasional good one from 2 feet of wet soil, and generally good yields with only occasionally a poor one from soil wet to a depth of 3 feet or more.

Belle Fourche

The Belle Fourche station, located near Newell, S. Dak., offers an unbroken record of 31 years, 1908–38, for plot A and 30 years for the other plots. The averages alone of the different groups are somewhat misleading. In the 12 years on plot A and the 13 years on plot B when available water was limited to the first foot section of soil, 46 and 43 percent, respectively, of the total yields were produced in 1915. When this year with unusually favorable conditions is eliminated from this group the average yields are 6.1 and 6.3 bushels, respectively. Soil moisture to a depth of 1 foot in the spring is not sufficient. With 2 feet of moist soil in the spring, the percentage of failures is held to a reasonably low point, and with 3 feet or more of moist soil, which is a common condition of fallowed land but infrequent on land cropped each year, the incidence of failure is very low.

Ardmore

During the period 1912–32, there are data for 16 years at the Ardmore station. Hail destroyed the crops in 1914 and 1922, and in 1921, 1923, and 1924 there were no soil-moisture determinations in the spring. At this station the dividing line between high risks with low average yields and low risks with satisfactory average yields rather clearly lies at or near the bottom of the second foot of soil

Scotts Bluff

The record at Scotts Bluff is short but rather consistent. With one exception only low yields were obtained from soils wet either 1 or 2 feet deep at seeding time. The record was much better, particularly on fallowed land, when the soil was wet to a depth of 3 feet or more.

Archer

Although crops were grown at the Archer field station in 1913–38 the data for only 6 years are available for the present study, because there were no soil-moisture determinations made in 1918 or after 1919. In none of the 6 years was available moisture limited to the first foot. As between 2 feet and 3 or more feet of wet soil the results in individual years are not very clear cut, but much higher average yields were obtained from the greater depth.

North Platte

Records covering an unbroken series of 28 years, 1907–34, are available from North Platte. Better average yields were obtained from 2 feet of moist soil than from 1, but available water to the depth of 3 feet or more in the spring assured much higher average yields and a high degree of safety. On land cropped to wheat each year the soil was wet in the spring to the depth of 3 feet in about 40 percent of the years, but on summer-fallowed land that condition obtained in all but 1 of the 27 years of record for that method.

Akron

Spring wheat has been grown on the Akron station each year since 1908, but soil-moisture determinations in the spring are available for only 11 years, 1908–17, and 1921. The number of years is small, and the data are not conclusive.

Amarillo

Amarillo offers data for 11 years, 1907–18. The location of the station was changed in 1910, and no data for the present study were obtained in that year. All yields were too low to encourage the growth of spring wheat, but yields were generally better with 2 and 3 feet of wet soil than they were with only 1 foot.

RESULTS AT ALL STATIONS

A summary of the study of the three methods of preparation of the land at all stations is given in table 1. The sums and averages in this table are brought together and further totaled and averaged in table 2. The average results at all stations are shown graphically in figure 2.

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TABLE 1.—*Number of years when the soil was wet to the depths specified and the average yields of spring wheat during those years on three methods of preparation at field stations in the Great Plains in the period 1907–38*

Station	Plot A, spring plowed, continuously cropped						Plot B, fall plowed, continuously cropped						Plots C and D, fallowed, alternately cropped					
	1 foot or less		2 feet		3 feet or more		1 foot or less		2 feet		3 feet or more		1 foot or less		2 feet		3 feet or more	
	Years	Yield	Years	Yield	Years	Yield	Years	Yield	Years	Yield	Years	Yield	Years	Yield	Years	Yield	Years	Yield
	Number	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*
Assinniboine	5	6.3	14	11.2	3	12.1	11	4.8	9	14.2	2	16.2	1	5.5	8	19.2	13	16.4
Williston	2	2.2	3	22.7	2	20.0	2	1.8	5	21.4	0	--------	0	--------	1	7.6	6	24.6
Huntley	12	4.7	12	10.3	2	17.5	13	3.5	11	11.4	2	13.0	3	4.4	13	8.1	10	18.4
Dickinson	3	6.5	11	14.3	7	17.2	4	7.6	5	12.5	12	15.9	1	5.7	3	18.1	17	25.1
Mandan (main field)	6	9.8	14	12.7	4	15.4	13	8.9	8	9.0	3	16.2	1	7.2	4	15.0	19	20.7
Mandan (south field)	11	7.8	7	11.3	2	7.8	2	3.2	1	0	3	18.0	2	15.9	8	12.5	10	16.9
Hettinger	4	5.7	3	22.9	1	4.2	6	9.4	1	12.0	1	5.5	0	--------	2	13.8	6	19.9
Sheridan	3	.5	7	8.4	11	16.8	3	0	9	11.7	9	17.8	1	2.7	1	5.3	19	22.9
Belle Fourche	12	10.3	14	11.9	5	11.9	13	10.2	12	12.2	5	23.0	0	--------	6	16.0	24	22.2
Ardmore	5	5.4	5	9.4	6	22.6	9	5.3	3	25.6	4	18.1	1	6.5	1	11.8	14	19.8
Scotts Bluff	3	3.7	3	7.2	3	9.9	2	8.4	3	6.7	4	8.6	1	.5	0	--------	8	16.8
Archer	0	--------	4	9.1	2	14.6	0	--------	5	7.2	1	23.7	0	--------	1	10.1	4	12.6
North Platte	8	6.0	8	10.0	12	16.0	3	8.0	14	9.6	11	18.1	0	--------	1	0	26	20.7
Akron	2	3.9	2	20.8	7	14.9	4	11.7	2	9.2	5	10.6	0	--------	1	16.2	10	13.0
Amarillo	3	.6	7	7.7	1	6.3	2	2.3	5	8.1	4	7.9	1	9.3	5	8.7	5	10.1
Total or average [1]	79	6.3	114	11.7	68	15.5	87	6.7	93	11.7	66	15.9	12	6.9	55	12.6	191	19.9

[1] Average of individual yields.

TABLE 2.—*Summary of number of years and average yields of each of three methods at all stations when the soil was wet to the depth specified*

Plot and treatment	Soil wet to—						Total years	Average yield [1]
	1 foot or less		2 feet		3 feet or more			
	Years	Yield	Years	Yield	Years	Yield		
	Number	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*
A, continuously cropped	79	6.3	114	11.7	68	15.5	261	11.1
B, continuously cropped	87	6.7	93	11.7	66	15.9	246	11.0
C and D, alternately fallowed	12	6.9	55	12.6	191	19.9	258	17.7
Total or average [1]	178	6.5	262	11.9	325	18.2	765	13.3

[1] Weighted averages.

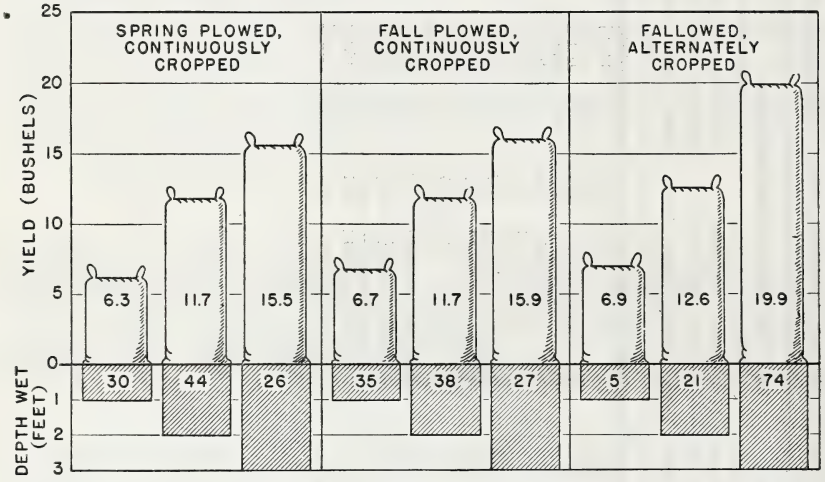

FIGURE 2.—Average yields of spring wheat at 15 field stations in the Great Plains when the soil was wet to different depths in the spring on three methods of preparation. (The figures in the depth blocks show the percentage of years when that condition obtained.)

The data cover a total of 261 station years on plot A, 246 years on plot B, and 258 years on plots C and D, a total of 765. The two continuously cropped plots, A, spring-plowed, and B, fall-plowed, are essentially duplicates for the purpose of this study when compared with the pair of plots, C and D, which are alternately cropped and fallowed.

The soil was wet in the spring to a depth of only 1 foot or less in 30 percent of the years on plot A, 35 percent on plot B, and only 5 percent on C and D. The average yields from this condition were 6.3, 6.7, and 6.9 bushels per acre, respectively. Yields of 15 bushels or more per acre were obtained but 12 times on plot A and 15 times on plot B (table 3). There has been less than 1 chance in 6 of producing a good crop when the depth of wet soil in the spring did not exceed 1 foot.

The soil was wet to a depth of 3 feet or more slightly less often than it was wet only 1 foot or less on the continuously cropped plots,

26 percent of the years on A and 27 percent on B; but 3 feet or more of wet soil obtained in 74 percent of the years on the fallowed plots C and D. The yields averaged 15.5 bushels on A, 15.9 bushels on B, and 19.9 bushels on C and D. These yields were 246, 237, and 288 percent, respectively, of the yields obtained from the same plots in the years when the available water in the spring was limited to the first foot of soil. The higher yield on the summer-fallowed plots than on the continuously cropped plots will be noted. The explanation for most of the increase is to be found in the fact that the summer-fallowed land contained available water below the third foot more often than did the continuously cropped plots. The authors have presented evidence on this point in another publication (*4, p. 65*). With only 1 foot or 2 feet of wet soil the average yield was only slightly higher on the fallowed plots than it was on the continuously cropped plots.

On land continuously cropped to small grain 2 feet of wet soil in the spring was a somewhat more frequent condition than either one of the other conditions, 1 foot or 3 feet of wet soil. The stated condition existed in 44 percent of the total years on plot A and 38 percent on plot B. On the summer-fallowed plots its occurrence fell to 21 percent. The yields as a class were intermediate, but on the continuously cropped plots they were somewhat closer to those on 3 feet of wet soil than to those on 1 foot. On continuously cropped land about 48 percent of the crops that were started on 2 feet of wet soil yielded 10 bushels or more, about 33 percent yielded 15 bushels or more, and about 22 percent yielded 20 bushels or more. On fallowed land the percentages were 58, 40, and 20, respectively, but 2 feet of wet soil in the spring occurs only about half as frequently on fallowed land as on land that is cropped each year.

At some stations, which is to say with some soils and precipitations, 2 feet of wet soil in the spring seems to be a fairly adequate condition, but at some other stations it does not provide a sufficient margin of safety or a level of production high enough to warrant seeding when that condition obtains.

It is not a primary purpose of the authors to present in this circular a study of cultivation methods or cropping systems as such, but it is impossible to avoid a comparison of alternate summer fallowing with continuous cropping to wheat. As averages of all stations and years, the crop on land that grew wheat every year began its growth about 3 years out of 4 on soil that was wet not more than 2 feet deep and only 1 year out of 4, on soil that was wet 3 or more feet deep. When seeded on land that had been summer fallowed the previous year, these figures were reversed and 3 years out of 4 the crop enjoyed the benefits of 3 or more feet of wet soil, and only 1 year in 4 was compelled to start on soil that was wet to a depth of 2 feet or less. The effects of these conditions on yields have already been shown.

The high frequency of an inadequate initial supply of soil water following a crop of wheat and the subsequent frequent failures or low yields and the generally low average yields that result from continuous cropping to wheat make this an entirely unwarranted practice at some stations, and at the best a questionable one at others where soil and precipitation are more favorable.

The high risk of failure attending the seeding of a grain crop when the stored water is not sufficient to have penetrated to a depth of more than 1 foot raises the question of what should be done when that

condition exists. The advent of rains may make conditions favorable for crops that may be seeded later, such as corn, sorghums, Sudan grass, millet, or small grain to be harvested for hay. Frequently, however, summer fallowing is likely to be indicated. A crop can then be sown on the fallowed land the following year. The yield of this crop may be compared with the sum of the two yields obtained if the land were seeded each year. The data in hand afford opportunity for 74 comparisons of 2 crops on spring-plowed land and 82 on fall-plowed land when the first crop had only 1 foot or less of wet soil with 1 crop on fallowed land the second year.

The average yield of the one crop on fallowed land was 93 and 94 percent, respectively, of the averages of the sum of two successive crops on spring-plowed and on fall-plowed land. In considerably more than half of the comparisons the single crop on fallowed land exceeded the total of the two crops on continuously cropped land. The slight loss in total production is much more than offset by the lesser cost of growing and harvesting one crop instead of two.

Other crops may enter into the rotation, the effects of which on the following crop generally lie somewhere in the field between those of continuous cropping to small grain and alternate fallowing and cropping. Thysell (*9*) has shown that corn may leave in the soil a residue of water that was unavailable to or unused by it but which may be available to a crop of wheat that follows. Among other crops having somewhat similar effect may be mentioned potatoes, beans, and small grains harvested in an immature state for hay. The effect of sorghums in the northern Plains or other short-season localities may be much the same as that of corn, but farther south where they have ample time to mature before frost they are not likely to leave in the soil any water available to wheat. Much of the residue of water left by such crops is apt to be in the lower depths of the feeding zone of wheat and consequently adds something to the effectiveness of the depth of soil that is wet to its field-carrying capacity by precipitation between harvest and seeding time.

There are occasional years when the precipitation, temperature, and other controlling factors are such that good yields are produced regardless of the cultural practices or the initial water content of the soil. On the other hand, there are years when conditions during the growing season are so unfavorable that only failures or low yields are realized, regardless of the initial condition. The first-named condition is of altogether too infrequent occurrence to base any expectation of continued success upon its appearance overcoming an unfavorable spring condition of soil water. Examination of the year-by-year results given in the appendix will show that only about once in 12 to 20 years at any of the stations studied will a good yield be obtained from wheat seeded on soil that is not wet more than 1 foot deep. Such an examination will also show the relative infrequency of failure from crops sown with the most favorable conditions of soil moisture. Both of the conditions named together are not frequent enough to destroy the practical value of the initial soil-water content as an indicator of production.

It seems self-evident that the success or failure of an agricultural system or practice must depend upon the average results that flow from it over a considerable period of years. Although temporary success may be achieved under abnormal conditions in spite of the

violation of fundamental requirements, the continued violation of such requirements can only result in ultimate disaster, as has been abundantly demonstrated in recent years.

SUMMARY AND CONCLUSIONS

Soil-moisture data at or near seeding time and the yields of spring wheat are available for a total of 261 station years at 15 stations in the Great Plains during the years 1907–38. With a few exceptions, data were obtained on three methods of cultivation, the total number of items being 765.

The nonavailable water of each soil having been determined in another study,[4] that knowledge was used to place each plot, or method, each year in one of three categories: (1) Soil wet 1 foot deep or less, (2) soil wet 2 feet deep, and (3) soil wet 3 feet deep or more, and the yields were assembled according to this placement.

Plot A, continuously cropped and spring-plowed, with 1 foot or less of wet soil in the spring 30 percent of the time averaged 6.3 bushels. With 2 feet of wet soil 44 percent of the time the average yield was 11.7 bushels, and with the soil wet 3 feet or more 26 percent of the time the average yield was 15.5 bushels.

The record of plot B continuously cropped and fall-plowed paralleled that of plot A rather closely. With 1 foot or less of wet soil 35 percent of the time the average yield was 6.7 bushels, with 2 feet of wet soil 38 percent of the time the average yield was 11.7 bushels, and with 3 feet or more of wet soil 27 percent of the time the average yield was 15.9 bushels. On plots C and D, alternately cropped and fallowed, an initial condition of 1 foot or less of wet soil obtained only 5 percent of the time, and the average yield from that condition was 6.9 bushels. The crop started on 2 feet of wet soil 21 percent of the time and averaged under that condition 12.6 bushels. The soil was wet 3 feet or more deep 74 percent of the time, and the yields from this condition averaged 19.9 bushels.

Under the limited precipitation of the Great Plains, the initial water content of the soil, which can be approximated by the depth to which the soil is wet, is a strong determinant of the yield that will be produced.

Frequent failures, low average yields, and very infrequent good yields from spring wheat seeded on soil that is wet only 1 foot deep or less clearly show that seeding when that condition exists is not warranted.

The results from seeding on soil wet 2 feet deep present a more favorable picture, being intermediate between those obtained when the initial depth of wet soil was either less or greater. Two feet of wet soil may provide a satisfactory margin of safety in some localities, but it does not in others.

The highest assurance of good yields is afforded by an initial condition of 3 feet or more of wet soil. This condition is much more frequent on fallowed land than on land that bore a crop the preceding year. The average yields from this condition are markedly higher on fallowed land than on continuously cropped land, chiefly because the depth of wet soil is frequently greater.

[4] Unpublished data in the files of the Division of Dry Land Agriculture.

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APPENDIX

Table 3.—*Annual and average yields of spring wheat by each of three methods when the soil was wet to different depths in the spring at 15 field stations in the Great Plains during the period 1907–38*

ASSINNIBOINE STATION, HAVRE, MONT.

Year	Plot A			Plot B			Plots C and D		
	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1916	------	45.8	------	------	47.5	------	------	49.3	------
1917	------	3.5	------	------	3.8	------	------	------	11.7
1918	------	------	5.7	------	4.7	------	------	------	5.8
1919	------	1.5	------	1.0	------	------	------	2.2	------
1920	7.2	------	------	7.5	------	------	------	10.5	------
1921	------	9.7	------	6.7	------	------	------	19.0	------
1922	------	7.2	------	0	------	------	------	------	12.2
1923	------	16.7	------	------	16.2	------	------	20.0	------
1924	------	11.8	------	7.3	------	------	------	------	19.0
1925	------	16.3	------	------	18.7	------	------	------	18.5
1926	------	------	4.3	------	------	1.7	------	------	13.5
1927	------	------	26.2	------	------	30.7	------	------	37.7
1928	------	16.0	------	13.0	------	------	------	------	41.3
1929	------	8.3	------	------	7.3	------	------	------	15.7
1930	------	2.2	------	1.5	------	------	------	------	11.3
1931	.8	------	------	0	------	------	------	3.0	------
1932	21.7	------	------	------	26.2	------	------	27.2	------
1933	.8	------	------	------	.7	------	------	------	12.8
1935	------	4.2	------	------	3.0	------	------	------	13.2
1936	------	0	------	.2	------	------	------	------	.3
1937	1.2	------	------	5.0	------	------	5.5	------	------
1938	------	13.2	------	10.3	------	------	------	22.7	------
Average	6.3	11.2	12.1	4.8	14.2	16.2	5.5	19.2	16.4
Number of years	5	14	3	11	9	2	1	8	13

TABLE 3.—*Annual and average yields of spring wheat by each of three methods when the soil was wet to different depths in the spring at 15 field stations in the Great Plains during the period 1907–38*—Continued

WILLISTON, N. DAK.

Year	Plot A			Plot B			Plots C and D		
	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1910	1.7			1.3					4.2
1911	2.7			2.3				7.6	
1912		25.2			33.8				39.7
1913			16.8		11.7				16.5
1914		23.8			22.5				31.2
1915		19.2			14.5				27.7
1916			23.2		24.3				28.0
Average	2.2	22.7	20.0	1.8	21.4			7.6	24.6
Number of years	2	3	2	2	5	0	0	1	6

HUNTLEY, MONT.

1912	11.0			7.8			7.8		
1913		16.0			11.8				22.7
1914		18.3			20.2				19.5
1915	24.5			25.3					36.5
1916	5.8			7.8				13.5	
1918		1.5				5.7			18.8
1919	0			0				.7	
1920			8.2		7.0				6.8
1921	3.0			1.3					17.7
1922		20.7			17.8			19.3	
1923	6.3				4.7			10.3	
1924			26.7			20.3			21.8
1925		7.0			5.7				10.0
1926		0		0				1.5	
1927		24.2			20.0			20.3	
1928	3.8				4.8				20.5
1929		2.8			4.2				9.7
1930	0			0				0	
1931	0			0			0		
1932		2.3			2.7			2.7	
1933	0			0				.5	
1934		0		0				4.5	
1935		1.0		1.2				2.5	
1936	0			.2				.2	
1937	2.0			1.5			5.5		
1938		30.3			26.5			28.8	
Average	4.7	10.3	17.5	3.5	11.4	13.0	4.4	8.1	18.4
Number of years	12	12	2	13	11	2	3	13	10

DICKINSON, N. DAK.

1907			37.0			31.6			28.3
1908		24.3				17.7			33.8
1909		26.8			25.2				35.7
1910			17.4			18.2			26.8
1911		5.7				1.4			23.3
1913			13.5			20.5			27.3
1915		25.8				28.7			38.7
1916			16.7		21.0				22.8
1917			5.5		2.7				12.3
1920	15.6			12.8				21.1	
1921	3.9			2.6			5.7		
1922		23.5				19.7			27.6
1923		10.3				12.3			14.8
1924			18.0			15.3			27.0
1925		4.5				7.0			20.0
1926	0			0				11.0	
1927		11.8			13.0			22.3	
1928			12.5	15.0					29.2
1930		7.3				5.0			20.0
1932		15.7				13.7			24.2
1933		1.8			.8				14.3
Average	6.5	14.3	17.2	7.6	12.5	15.9	5.7	18.1	25.1
Number of years	3	11	7	4	5	12	1	3	17

TABLE 3.—*Annual and average yields of spring wheat by each of three methods when the soil was wet to different depths in the spring at 15 field stations in the Great Plains during the period 1907–38*—Continued

MANDAN (MAIN FIELD), N. DAK.

Year	Plot A			Plot B			Plots C and D		
	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1915	30.5			32.1					39.3
1916			19.2			18.5			21.8
1917			15.3			14.8			17.2
1918		12.7				15.3			32.0
1919		7.5			5.3				15.7
1920	1.5			1.0					9.5
1921	1.8			0				3.5	
1922		19.5			12.2				29.0
1923		8.3			2.8				14.2
1924		21.5		15.8					29.3
1925		18.5			14.2				31.2
1926	1.0			0					9.0
1927	22.2			21.2				31.7	
1928		15.5		16.2					22.8
1929			13.8		9.0				20.2
1930		10.2			4.2				23.8
1931			13.2		2.8				19.3
1932		26.0			21.2				34.8
1933		0		0					5.3
1934	1.5			0				5.5	
1935		22.7		20.7				19.3	
1936		0		0					0
1937		4.0		2.2			7.2		
1938		10.8		6.0					19.3
Average	9.8	12.7	15.4	8.9	9.0	16.2	7.2	15.0	20.7
Number of years	6	14	4	13	8	3	1	4	19

MANDAN (SOUTH FIELD), N. DAK.

1915		29.3				30.4			45.3
1916			15.5			17.8			11.8
1917	7.3			6.3					13.8
1918			0		0			3.8	
1919		6.3				5.8			13.0
1920	0			0					10.0
1922		17.5						16.3	
1923	5.0							16.0	
1924	13.3							16.3	
1925	10.0								21.0
1926	0							2.3	
1927	20.0						30.8		
1928	8.0								24.3
1929		5.2							12.2
1930	4.7								14.7
1931		4.0						9.0	
1932	17.8							21.8	
1933		0							2.8
1934	0						1.0		
1935		16.5						14.3	
Average	7.8	11.3	7.8	3.2	0	18.0	15.9	12.5	16.9
Number of years	11	7	2	2	1	3	2	8	10

HETTINGER, N. DAK.

1912		14.3			12.0			17.5	
1913		13.8		10.7					37.0
1914	10.0			6.2				10.0	
1915		40.7		29.3					37.5
1916			4.2			5.5			4.2
1917	5.2			1.7					16.8
1918	7.5			8.5					13.5
1919	0			0					10.5
Average	5.7	22.9	4.2	9.4	12.0	5.5		13.8	19.9
Number of years	4	3	1	6	1	1	0	2	6

TABLE 3.—*Annual and average yields of spring wheat by each of three methods when the soil was wet to different depths in the spring at 15 field stations in the Great Plains during the period 1907–38*—Continued

SHERIDAN, WYO.

Year	Plot A			Plot B			Plots C and D		
	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1917		6.5			5.3			5.3	
1918			21.1			23.1			29.2
1919	0.6			0					3.3
1920			16.2			20.5			23.5
1921	1.0			0					7.0
1922			22.7		24.5				34.2
1923		13.7			15.2				24.8
1924			20.8			21.8			27.2
1925			17.2			18.2			30.8
1926		7.3			5.8				25.3
1928			22.5		21.5				42.2
1929			13.7			13.8			26.8
1930		4.8				8.8			20.8
1931	0			0			2.7		
1932			20.7			23.8			30.8
1933			9.5			10.0			19.0
1934		1.3			1.2				15.0
1935			7.0		6.2				13.0
1936		0			0				3.5
1937			13.5			20.2			19.7
1938		25.2			25.7				39.7
Average	.5	8.4	16.8	0	11.7	17.8	2.7	5.3	22.9
Number of years	3	7	11	3	9	9	1	1	19

BELLE FOURCHE, S. DAK.

1908		23.3							
1909	23.8			23.3					32.2
1910		2.8			0				5.0
1911			0		0			0	
1912		0		0				0	
1913		6.2			7.9				16.8
1914	4.0			4.8					15.8
1915	56.5			57.7				57.2	
1916		10.6		10.8					18.7
1917	4.4			2.8					11.1
1918		8.5			9.8				35.0
1919	0			0					6.2
1920			29.2			28.7			29.2
1921	3.8			2.0					25.0
1922		29.0			30.0				31.5
1923			4.8			28.5			31.0
1924			11.8			19.5			23.8
1925		6.2			15.2				24.5
1926		23.0			29.3				45.2
1927			13.8			12.3			25.5
1928		20.3				26.2			41.7
1929		17.2			23.5				29.7
1930		5.2			6.7				17.7
1931	0			0					.8
1932	17.0			15.5				18.8	
1933		12.0			14.5				19.8
1934	4.5			10.7					21.3
1935		2.8			2.8				10.5
1936	0			0				1.0	
1937	7.3			5.3				18.7	
1938	2.2				6.2				15.3
Average	10.3	11.9	11.9	10.2	12.2	23.0		16.0	22.2
Number of years	12	14	5	13	12	5	0	6	24

TABLE 3.—*Annual and average yields of spring wheat by each of three methods when the soil was wet to different depths in the spring at 15 field stations in the Great Plains during the period 1907–38*—Continued

ARDMORE, S. DAK.

Year	Plot A			Plot B			Plots C and D		
	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1912	3.3			3.2			6.5		
1913	2.3			0					7.2
1915			49.2		49.5				45.0
1916			18.0			17.5			15.8
1917			7.5	5.5					8.7
1918		27.7			24.2				37.0
1919		3.3			3.0				10.3
1920			23.8			20.0			23.7
1925	7.3			11.7					16.3
1926		5.7		5.3				11.8	
1927			33.5			32.8			37.2
1928		9.5		10.7					32.2
1929	5.7			2.8					17.8
1930			3.8	3.2					10.7
1931		1.0				2.2			2.5
1932	8.5			5.3					13.3
Average	5.4	9.4	22.6	5.3	25.6	18.1	6.5	11.8	19.8
Number of years	5	5	6	9	3	4	1	1	14

SCOTTS BLUFF, NEBR.

1911	0.5			0.5			0.5		
1912		8.7			6.3				22.5
1913			12.0			7.8			17.3
1914	5.7					6.7			11.7
1915	5.0			16.2					12.5
1916			5.5			5.7			11.2
1917		9.2			7.0				18.7
1918		3.7			6.7				21.3
1920			12.3			14.0			19.3
Average	3.7	7.2	9.9	8.4	6.7	8.6	.5		16.8
Number of years	3	3	3	2	3	4	1	0	8

ARCHER, WYO.

1913		10.3			10.0				
1914		6.8			7.5			10.1	
1915			26.8			23.7			25.7
1916			2.3		2.4				2.8
1917		15.6			13.6				14.9
1919		3.5			2.5				7.1
Average		9.1	14.6		7.2	23.7		10.1	12.6
Number of years	0	4	2	0	5	1	0	1	4

TABLE 3.—*Annual and average yields of spring wheat by each of three methods when the soil was wet to different depths in the spring at 15 field stations in the Great Plains during the period 1907–38*—Continued

NORTH PLATTE, NEBR.

Year	Plot A			Plot B			Plots C and D		
	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet	1 foot	2 feet	3 feet
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1907			24.5			26.0			31.8
1908			22.7		27.3				40.5
1909			23.0		15.3				18.0
1910			6.8		6.7				18.3
1911	0			0				0	
1912			12.8			11.2			10.5
1913		2.0			1.8				10.0
1914		6.0			5.2				15.2
1915		22.7			22.8				27.8
1916			17.2			17.5			19.8
1917		4.2			5.2				18.7
1918		3.7			2.2				18.5
1919			15.5		13.0				16.7
1920			16.5			18.8			21.2
1921	6.5					10.2			17.3
1922	2.3				3.3				12.8
1923	17.0			20.2					22.0
1924			14.8			21.5			23.0
1925		6.3			4.7				24.0
1926	0				0				14.3
1927			16.2			17.7			21.5
1928	17.5				26.3				33.7
1929		12.2				19.8			26.3
1930		23.0				26.8			28.7
1931			12.7			16.7			
1932	5.0			3.8					26.0
1933			9.8			12.5			16.7
1934	0				0				3.8
Average	6.0	10.0	16.0	8.0	9.6	18.1		0	20.7
Number of years	8	8	12	3	14	11	0	1	26

AKRON, COLO.

1908			17.3			14.0			13.7
1909			14.3			10.3			18.5
1910			11.3		6.2				8.5
1911	2.9					4.1			4.7
1912			21.3			20.7			16.0
1913	4.8			0.8					5.7
1914		22.2			12.2				14.2
1915			26.3	25.8					33.8
1916			9.3	3.8					12.3
1917		19.3		16.2				16.2	
1921			4.3			4.0			2.5
Average	3.9	20.8	14.9	11.7	9.2	10.6		16.2	13.0
Number of years	2	2	7	4	2	5	0	1	10

AMARILLO, TEX.

1907		2.5			1.7			2.8	
1908		17.0			14.0			16.0	
1909	0			2.8				10.5	
1911		7.3			10.0				19.0
1912			6.3			8.5			9.5
1913	0			1.8			9.3		
1914		11.0				12.8			13.8
1915		12.4			11.0			11.6	
1916		3.5				7.0			4.7
1917	1.7				3.8				3.5
1918		0				3.2		2.8	
Average	.6	7.7	6.3	2.3	8.1	7.9	9.3	8.7	10.1
Number of years	3	7	1	2	5	4	1	5	5

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